Solar & propane powered SUPER HOME

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South facing passive solar heated greenhouse and two solar photovoltaic arrays

My initial goal was not to build a solar home. My goal was to build a home so energy efficient it could easily operate on only solar electricity and propane heat. I also did not want to worry about problems with power outages. Since we are located only a few miles from Richmond, Virginia, we were one of the many homes in the direct path of recent Hurricane Isabel, which provided the acid test for my designs.

While many Virginia residents and neighbors waited up to two weeks for power and water to be restored, our home's automatic power system took over control to meet all of our energy requirements until the local power grid was restored. Technically speaking, we are still connected to the local electric utility. However, our home's grid power is used only to power our outbuildings and the central air conditioning system, a real necessity during most of Virginia's very humid summers. The utility grid is also utilized to power the clothes washer and whirlpool during periods of cloudy or rainy weather when the battery charge is low and we do not want to start the generator. There are many months when our electrical bill is less than 500 kilowatt-hours, or about $30 for a 3,300 square foot three-story home. In fact, the amp meter monitoring all 120-volt lighting and appliance loads operating at any one time rarely exceeds a total of 6 amps.

Heating design

A 500-gallon underground propane tank is used to supply a commercial six-burner kitchen stove, backup 6.5 kW generator, clothes dryer, and a 48-gallon super efficient hot water tank.

It is interesting to note that we do not have a gas furnace or conventional heating system. The air conditioning ductwork and air-handling unit include two hot water coils located just downstream from the central fan and filter unit. One coil is piped to a small circulating pump and the hot water tank. When the wall thermostat calls for heat, the control system turns on the central fan and circulating pump which moves hot water from the top of the hot water tank

High ceiling living/dining area and large south facing windows provide passive winter solar heating.

through the first hot water coil to heat the air being distributed to the house. This water flow returns to the bottom of the hot water tank for reheating through a motorized valve that prevents hot water flow when the air conditioning system is operating.

The second hot water coil is piped to a second circulating pump and a hydronic water jacket built into our masonry fireplace. When a fire is started in this downstairs fireplace, the control system senses the heat and starts the circulating pump to heat the air being distributed to the house. Since this water jacket is very efficient in removing the fire's heat, we do not have the typical problem of being very hot just in front of the fireplace while the rest of the house is cold. As long as we keep the fire going on a cold night, the entire house stays the same warm temperature throughout using only wood for fuel. If we are lazy and do not feel like keeping a fire going, the controls switch back to the primary hot water coil and hot water tank.

We also have an old-style cast iron kitchen stove in our living/dining room area which provides wonderful fire sounds and heat during frosty mornings, while keeping the coffee pot and breakfast biscuits hot. This new stove was made from the original 1800's casting patterns and can produce an amazing amount of heat without smoking, while using only a few sticks of kindling. We actually cook all meals in our modern kitchen. I am just too lazy to build a fire each morning to cook breakfast, but this kitchen woodstove does make a great place to read the paper on Saturday mornings.

Home construction

We are often asked how a small 65,000 BTU hot water tank can supply all of the hot water for three bathrooms, the kitchen, both clothes and dishwashers, and still be able to heat a three-story house. The answer is super-efficient appliances and double-exterior wall construction. In order to minimize the exterior wall surface heat loss and still have over 3,000 square feet of living area, the interior is divided into three floors with the first floor partially below grade, and the top master bedroom and bath floor located within peak of the high pitched roof. A single story house this size would have almost three times the exterior surface area.

The reduced exterior wall area utilizes what I refer to as double-envelope construction. Two separate 2x4 walls were built with the studs spaced alternately on 2x6 top and bottom plates, allowing the voids created to be filled with an R-24 level of batt insulation. Since the exterior wall surface is attached to the exterior studs and the interior drywall is attached to the interior studs, there is no "wicking" effect where heat is transferred from one side to the other through a conventional wood single layer stud wall. All windows are super insulated low "e" double glazed, argon gas filled thermal glass with crank out type double latch operation. This provides a much tighter air seal than double sash windows when closed. The ceiling/roof construction has an R-36 level of insulation. To reduce energy wasting air infiltration, all foundation, wall, and window frame connecting joints were carefully caulked.

The house includes a 300-square-foot greenhouse on the south side that is totally heated by passive solar heat. Unlike a traditional uninsulated single glazed greenhouse, this greenhouse has double glass glazing and

Home theater with built-in six-channel sound system shows how a solar-powered home can have all the modern conveniences.

high thermal mass concrete walls and floor that provide a very stable temperature range without any conventional heating. Even during the coldest nights it rarely drops below 55 degrees, and most days and nights it stays in a comfortable 70 to 80-degree range. During the summer a solar-powered side exhaust fan pulls outside air through above grade louvers along the exterior wall to prevent overheating.

Home appliances

Although our major appliances appear to be what you see in any appliance store, they had to be custom ordered and were the most energy efficient models available from their manufacturer. Many were designed for export to countries having much higher utility costs and are not usually sold in the United States due to their higher initial cost. We also recognized that these appliances would be powered from a combination of solar power, generator power, and utility grid power, and switching

24-volt DC powered fluorescent wall sconces for corridors and stairwells

from one energy source to another was a concern. We made it a high priority to select appliances that utilized simple mechanical dial type timers and manual controls. This avoided complex microelectronic display panels and operating programs that could go haywire every time there is a "blip" on the power line. This also helped to reduce "phantom loads" from all those electronic display panels and remote controls that stay on 24 hours per day, even when this appliance and audio video equipment is not being used.

This search for the most efficient major appliances also carried over for all television and stereo components. Since our home includes a built-in home theater with large projection screen, six-channel sound system, and every audio and video source imaginable, each item was carefully chosen for the highest energy efficiency. When shopping for these items, we took a portable digital wattmeter with us. I was amazed to find that some brands and models of video equipment consumed the same electrical power regardless of being turned on or off. My only conclusion is the on/off switch is only connected to the tiny LED indicator light.

Anytime you are trying to minimize energy consumption in a home, reducing phantom loads and small loads that operate continuously is critical. For example, a typical 35-watt dual lamp exit light that you see operating 24-hours per day in almost every commercial and institutional building hallway consumes 613,200 watt-hours of electricity per year, or 51 kWh's per month. This light fixture load may seem small at first, but this would require a 340-watt solar array dedicated to power just that single light fixture, assuming five hours of clear sky sunlight every single day.

(340 watts x 5 hrs. x 30 days
= 51 kWh/month)

I doubt that you need a lighted exit sign in your home, but this is just an

Custom-made SunFrost 24-volt DC powered refrigerator/freezer

example of how a very small electrical load that operates continuously can consume up to 25 percent of a typical 1,500-watt residential size solar array. Think of all those cell phone chargers, portable phones, computers, digital appliance displays, clocks, and instant-on electronic equipment left plugged in 24 hours per day in your own home.

This is why you will almost never find an electric hot water tank, electric stove, air conditioner, portable heater, pool pump, whirlpool, or electric clothes dryer in any off-grid solar powered home. The added cost for additional solar modules and batteries that would be required to power these high amperage appliances would be hard to justify on an economic basis, unless you have extremely high electric rates in your state. These larger heating appliances will most likely either be propane or natural gas fueled, or only operated when a backup generator or utility grid is available. Reasonably priced solar hot water heaters are also available, but you would still need an electric or gas backup water heating source. We are

All bathroom lighting is recessed halogen controlled by motion sensors.

often asked about the high power demand for a microwave oven. These do require up to 2,000 watts to power. However, a microwave oven can heat up a meal or drink in seconds, so the actual total metered kilowatt-hour consumption (power x time) is still much lower than operating a conventional heating element for a much longer period.

Another large energy using appliance found in all homes is the refrigerator, and many are very inefficient. Since we live in a small rural area, we knew we would not be running to the store every day, so we needed lots of freezer and refrigerator space. After measuring the high-energy consumption of most standard refrigerators and freezers, we selected a custom-made SunFrost 24-volt DC refrigerator for the kitchen and SunFrost 24-volt DC freezer for our utility room. Since both units have DC compressors, they are powered directly from our large battery bank and will still operate even if all other electrical systems have failed.

We special ordered a very efficient high flow 120-volt AC well pump that can be powered from the inverter, generator, or utility grid. We also used oversized piping, and a very large well pressure tank which substantially reduces the number of energy-wasting pump starts. The piping design also reduced the number of 90-degree pipe fittings and located all water using fixtures near each other which lowered pumping energy even further. The well also includes an emergency low flow 24-volt DC submersible well pump that can operate directly from the battery if the primary AC pump or its power supply fails.

Lighting design

Skylights with motorized shading devices were located to provide indirect day lighting to interior spaces which minimizes the need for artificial lighting. All surface and recessed lighting fixtures were located to maximize their illumination area and minimize their wattage. No standard incandescent light bulbs or frosted lens covers were used in the entire house. Dimming recessed halogen 40-watt PAR fixtures were used in the high ceiling living room, bathrooms, and home theater. Surface mounted fluorescent fixtures were used in the kitchen, greenhouse, home office and utility room. Compact fluorescent 13-watt twin tube fixtures were used for all bedrooms, corridors, and stairway wall sconces, and compact fluorescent bulbs were used in all table lamps. All fluorescent lamps were ordered from a lighting specialty supplier in order to provide matching "warm" color spectrum lighting throughout the house. These fluorescent lamps do not have the typical harsh blue white light found with lower cost shop and office type fluorescent lamps.

We have motion sensor controlled lights in all bathrooms and corridors to minimize lighting operating time in these areas, that sometimes surprise our weekend guests. Being in the shower where the motion sensor cannot sense motion will cause the lights to turn off after a few minutes. Waving your arm outside the shower curtain will quickly turn the lights back on, but for the most part everything in our home works and appears to be the same as any conventional home.

Wiring design

The solar wiring design for our home is more easily understood by explaining one subsystem at a time. Grid electricity enters from the out-

Trace 4 kW power inverter which converts battery power into 120-volts AC

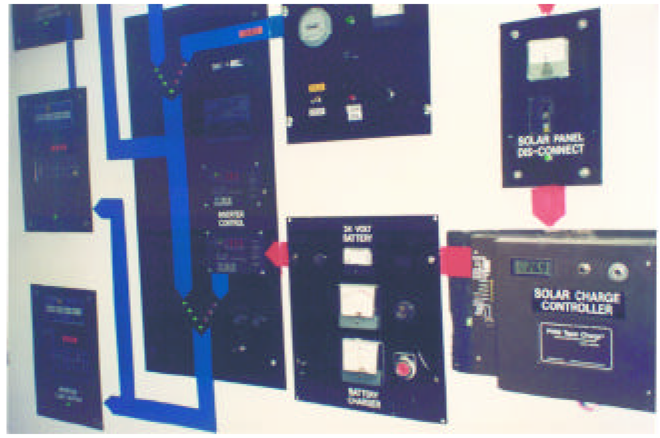
side utility meter at the "Main House" panel, which has circuit breakers supplying the 240-volt central air conditioner, pool pump, and all outbuildings. A 60-amp circuit breaker feeds the "Emergency Loads" circuit breaker panel through transfer switch "A." The generator also supplies transfer switch "A," allowing either the utility grid or the generator to supply power to this panel. These loads include the whirlpool, dishwasher, clothes washer, clothes iron outlet, and small air conditioner serving the master bedroom and bath. The generator also feeds the "Critical Loads" panel through transfer switch "B," which is part of the 4-kW inverter. The DC battery power that is converted into AC electricity by this inverter also supplies the "Critical Loads" panel, which feeds all wall outlets, phones, lighting circuits, well pump, home office computers, fax machine, kitchen appliances, and all audio/video equipment. These loads can be supplied from the utility grid, generator, or inverter, and are those "must have" loads we cannot do without.

Since transfer switch "B" in the inverter is extremely fast. Any loss of grid or generator power causes an immediate switch to battery power for these critical loads without any power interruption. In addition, as long as the battery bank is fully charged, all of these loads will be operating from solar-charged battery power which significantly reduces our monthly purchase of grid electricity.

A small DC circuit breaker panel supplies all low-voltage DC loads. These include fluorescent wall sconces in the stairwell and hallways; the refrigerator, freezer, and greenhouse exhaust fans; and emergency service lighting fixtures located in the battery room and generator area. Since no electronics are required to operate this low voltage lighting (not counting fluorescent ballasts), these lights and appliances are considered virtually fail-safe, as long as there is charge left in the battery bank. A major failure of the solar array, power inverter, utility grid, or generator will still not prevent the operation of these 24-volt D.C. loads.

Since the majority of our home's lighting and appliances operate from the inverter using solar-charged battery energy, staying off the grid depends on keeping this battery charged. Located on the south side of our home above the greenhouse are 28 solar modules that can generate 1,200 watts in full sun. Immediately beside the greenhouse are 16 larger ground-mounted solar modules that generate an additional 1,200 watts for 2.4 kW total. Each solar array has its own solar charge controller that regulates the battery charging process, and a failure of one array or charge controller does not affect the other. We also have a 400-watt wind generator that provides additional battery charging during stormy weather when heavy cloud cover has blocked normal solar battery charging. Even if we did not have a solar and wind charging system, both the generator and utility grid can recharge the battery bank through the inverter.

During a grid power outage, if the battery bank charge level drops below a preset minimum, the control system will automatically start the generator and supply all our electrical needs while recharging the battery bank, a process that takes approximately three to four hours. As soon as the battery is fully charged, the control system stops the generator, and the inverter continues to supply all critical electrical loads. Operating our home without any grid power or during an extended period of stormy weather typically requires running the generator two hours during morning showers and breakfast preparation, and another two hours during evening dinner preparation and entertainment activities. The house can coast through the rest of the day and all night on just battery power. This eliminates the problem with portable high fuel consumption and noisy backup generators operating 24 hours per day during a power outage. Since the generator operates on propane fuel supplied from our large underground tank, I never need to deal with gasoline that has gone bad or refilling the fuel tank every few hours.

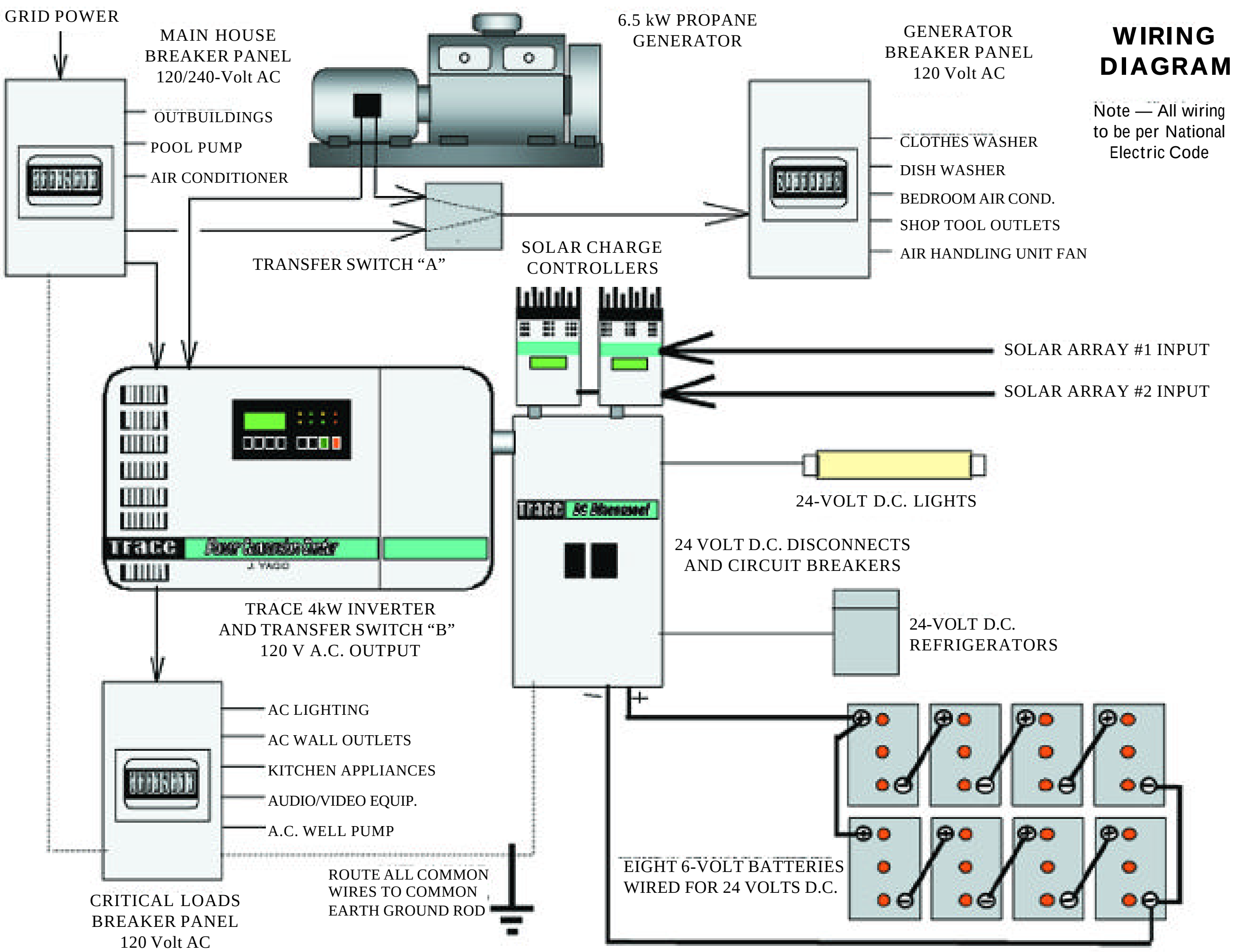


Control room with LED panel lights and meters to indicate direction and status of all power flows

We are currently planning to install another 2,400 watts of solar array which will be installed on our garage addition currently under construction. The 800 AMP-Hr 24-volt battery will also double in size.

Lifestyle changes

Operating a solar home that is still connected to the utility grid requires only minor changes to your lifestyle. Other than periodic battery and generator maintenance, there is little to do. However, if you choose to live totally off the grid, or only use the grid for summer air conditioning



Wiring diagram

loads, as we do, there will be some lifestyle changes required.

You will no longer be able to turn on a major appliance or power tool whenever you want without first checking the battery gauge, usually located in the kitchen. You will be more aware of the local weather forecast before washing the car or watering the garden which require heavy water pumping loads. Sunny days will be planned for cleaning, clothes washing, or using power tools, while cloudy weather will necessitate activities having much lower energy needs. It is certainly possible to have a solar array and battery large enough to carry you through a week of cloudy days with no need to alter your energy usage patterns. In reality, an array and battery system this size could cost up to half the cost of the home which, for most homeowners, probably cannot be justified.

Conclusions

A well designed solar powered home having the most energy efficient appliances and lighting does not need to be a cramped cabin without any labor saving appliances. In fact, most guests do not realize the sun powers our home until they see our battery control room. Most do not even notice the large solar array across the front of our home, and I can only assume they must think it is a really big skylight.

The biggest difference between living in an alternative energy home and a conventional home is your lack of concern for a power outage or high electric bills. I can also assure you that today's daily news of terrorist infrastructure attacks and multistate utility outages will no longer worry you. You will, however, become a Noah's Ark for your extended family during any emergency, so make sure the freezer is well stocked.

(Jeff Yago's latest text titled, *Achieving Energy Independence—One Step at a Time*, provides a very good introduction to off-grid living and solar photovoltaic power systems. It is available from the *Backwoods Home* bookstore or by calling 804-457-9566.) Δ